INSTITUTION OF GAS ENGINEERS

Our Abstracts of Reports to be presented at the Autumn Research Meeting on Nov. 7 and 8 at the Institution of Mechanical Engineers

Tenth Report of the Gas Education Committee—1932-33

The Education Scheme; 1924-1933.

The only Examinations available up to 1923 were conducted by the City and Guilds of London Institute, which took over from the Royal Society of Arts in 1879; but for four years a Committee appointed by the Institution in 1919, had been preparing a comprehensive Scheme for the education and certification of the personnel of the Gas Industry, with special regard to providing the qualifications which, amongst others, would be necessary for admittance to the Institution.

The Courses of the City and Guilds of London Institute in Gas Manufacture and Gas Supply were amended and modified by the Institute in 1925, and are now conducted as Minor Grade Courses in Gas Works Practice and Gas Supply Practice. They are particularly suitable for those who do not wish to qualify for professional status. Later the Course in Gas Fitting was modified and is now intended for craftsmen.

In 1923, the Committee submitted, with the approval and co-operation of the Board of Education, a Scheme for the award of Grouped Course Certificates in Gas Engineering and Gas Supply, which were recognized by the Royal Charter to the Institution as part qualification for membership.

The growth of the education work of the Institution during the ten subsequent years can be measured from the fact that at the end of the first year in 1924, 36 Internal Students were presented by four Approved Centres for examination and 24 External Students were examined, a total of 60 candidates, whilst in 1933, 312 Internal Students were submitted by 26 Approved Centres for examination and 105 External Students were examined, a total of 417 candidates. There are now 43 Approved Centres for Major Courses in Gas Engineering and/or Gas Supply compared with 11 Approved Centres in 1924.

The tuition provided by the Technical Colleges throughout the country in Gas Subjects has improved appreciably, largely due to the Short Course for Teachers in Gas Engineering and Gas Supply which has been held annually since 1927, under the auspices of the Board of Education. The Courses have been organized and conducted by Mr. C. H. Creasey, H.M.I.

Approximately 80 per cent. of those actually teaching in the country have attended the Teachers' Course, but there are still many Undertakings which could, with advantage to themselves, afford facilities for the attendance of those members of their Staffs who are Teachers or intending Teachers in Gas Subjects.

Administration.

The increasing number of candidates who re-sit an Examination and fail to pass or improve their position, would indicate that students should not readily be granted exemptions prior to such Examinations. Exemption from the whole or part of the three years' Course for the Ordinary Grade Certificate is not necessarily in the Student's best interests, neither is the taking of a Final Examination before a candidate is fully prepared.

The number of candidates for the Gas Fitting Examinations conducted by the City and Guilds of London Institute, in co-operation with the Institution, has increased to such an extent that difficulty has been experienced in securing a sufficient number of suitable Examiners for the Practical part of the Examinations. Gas Engineers and Managers, when approached by the District Gas Education Committees, are urged to release suitable men to undertake this work, since the proper qualification and certification of those who come frequently into contact with the consumer is of the utmost importance.

Examination Results, 1933.

A Comparative Statistical Schedule of the 1932 and 1933 Examination Results shews that the increase of 37 per cent. in the number of candidates sitting in 1932 over those who presented themselves in 1931 has been maintained.

The Charles Hunt Memorial Medals were not awarded in the 1933 Examinations.

In regard to the Examinations in the Minor Courses in Gas Works Practice and Gas Supply Practice and in Gas Fitting, the number of candidates in the three Grades of Gas Fitting was approximately the same as in 1932. Whilst there was a decrease in the number of candidates in Grade I, there was an increase in the number of candidates in Grade II and the Final Grade.

Report of the Board of Examiners.

The Report of the Board of Examiners indicates that candidates, in many cases, are unable to relate their knowledge of the Ancillary Subjects to the Main Subjects of Gas Engineering and Gas Supply. The need for

a sound general education is again emphasized, and clarity of expression and sketching are two matters which require special attention.

Approved Courses.

The following additional Courses have been approved by the Board of Education and the Gas Education Committee during the year:

4 Courses in Gas Engineering—Ordinary Grade.
1 Course in Gas Engineering—Higher Grade.
3 Courses in Gas Supply—Ordinary Grade.

Five additional Courses in Gas Fitting have been approved by the Gas Education Committee during the year.

Examinations, 1934.

The next Examinations in Gas Engineering will be held on 28th April, 1934, and in Gas Supply on 5th May, 1934. Entries must be received by the Secretary of the Institution not later than 28th February, 1934.

Notification of an External Candidate's intention to present himself for examination in a Subject ancillary to Gas Engineering or Gas Supply must be received by the Secretary not later than 15th January in each year.

Students have to comply with the Regulations in force at the time of their Examination, and "Permission to Sit" is given only in respect of the Examination to be held next after such permission is granted.

Corrosion from Products of Combustion

[33rd Report of the Joint Research Committee]

Research Chemist: JAMES W. WOOD, M.Sc.Tech., A.I.C. *Research Assistant:* E. PARRISH, M.Sc.Tech.

The investigations carried out by the Joint Research Committee of the Institution and Leeds University over a period of years shew that modern gas appliances operate with a high degree of thermal efficiency, and that when correctly adjusted they are hygienically sound. A certain amount of trouble is, however, experienced with the corrosion of gas appliances by products of combustion, and the Committee is directing its attention to this important problem, the present Report being an account of preliminary investigations into the subject. The work should be of great interest to the gas industry, for corrosion may involve interruption of service, maintenance and replacement charges, and an unattractive appearance of appliances. The trouble has become more noticeable with the development of the water-heating and central-heating loads.

It is usually assumed that the sulphur compounds in the gas, or rather their oxidation products, are in the main responsible for the corrosion, and some idea of their concentration can be obtained when it is pointed out that 100 cu.ft. of typical gas containing 25 grs. of sulphur will produce 0·04 cu.ft. of sulphur dioxide; the theoretical (air-free) products of combustion will therefore contain about 0·01 per cent. of sulphur dioxide, and the actual flue gases a correspondingly smaller proportion according to the volume of excess air passing through the appliance. In addition about 1 cu.ft. of water vapour will be produced for each cubic foot of gas burned.

The production of this water during combustion is unavoidable, and is an important factor in corrosion phenomena. It is frequently assumed that if the flue gases passing through an appliance are not cooled below the dew-point, so that condensation does not take place, then corrosion will be prevented. Corrosion is certainly reduced by adopting this course, and several British and Continental water-heaters are protected in this way, although it involves a loss in thermal efficiency of some 10—12 per cent. on the gross calorific value.[1] Care must be taken that the products of combustion do not fall below the dew-point before their *final* discharge into the atmosphere, otherwise one may only be transferring the seat of trouble from the appliance itself to a flue-pipe or chimney stack. Even in the most successful of these non-condensing heaters it is impossible to avoid momentary condensation when the appliance is started from cold, and while the *average* temperature of the exit gases may be well above the dew-point, the layers of gas in contact with the flue walls may be sufficiently cooled for some condensation to take place there. It is important to determine experimentally whether or not condensation is an essential preliminary to corrosion.

It is not an easy matter to say in advance what will be the nature and strength of the acid condensate. This will depend upon the temperature, the proportion of water condensed, the amount of sulphur in the gas, and the relative proportions in which the sulphur compounds of the gas are oxidized to SO_2 and SO_3 respectively.

Consideration of a particular case discloses some interesting facts. Let us take a very efficient water-heater, such as a calorimeter, condensing some 20 c.c. of water per cu.ft. of gas burned, and assume that the whole of the sulphur (taken at 25 gr./100 cu.ft.) is burned to SO_2, with a resultant concentration of 0·01 per cent. of SO_2 by volume in the flue gases. If saturated with SO_2 at 15° C. and 760 mm. pressure, this condensate is capable of taking up 940 c.c. of SO_2, but at the low concentration of 0·01 per cent. only 0·094 c.c. would be absorbed, *i.e.*, 0·269 mg., or a maximum concentration of approximately 0·0014 per cent. of SO_2 by weight in the condensate—a very dilute solution of SO_2. Incidentally, this would represent a removal of only 0·8 per cent. of the sulphur by the simple solution of SO_2 in the condensate, under conditions comparatively favourable for absorption.

In making the above calculations it has been assumed that Henry's Law for the solution of gases is valid at low partial pressures. There is a dearth of experimental evidence on this point. The solubility is influenced by ionization and the presence of CO_2, and is probably slightly greater than the values calculated above, but not sufficiently greater to invalidate the view that the solution of SO_2 must be a very dilute one, and that the removal of SO_2 by simple solution is of a very low order.[2, 3]

If, on the other hand, the whole of the sulphur were oxidized to SO_3, the situation would be quite different. This compound unites with water to form the more stable sulphuric acid, and there would be no difficulty in retaining the whole of the sulphur with the amount of water produced by combustion. In the case considered, but substituting SO_3 for SO_2, the condensate would contain 0·25 per cent. by weight of sulphuric acid. Despite the great affinity of SO_3 for water, efficient scrubbing arrangements are essential for its removal with a limited amount of water, on account of the tendency to form a mist with vesicles of acid which do not readily coalesce.

The figure given above, namely, 0·25 per cent., does not represent the maximum concentration of sulphuric acid which must be considered. It would be theoretically possible to wash out all the SO_3 with a much smaller amount of water than the 20 c.c. per cu.ft. produced by combustion; in conditions where only a portion of the water is condensed, therefore, a corresponding increase in the strength of the acid condensate could be expected.

[1] See 25th Report of the Joint Research Committee, 1930.

[2] For solubility of SO_2 see International Critical Tables, Vol. III., 1928, p. 258.

[3] See also "The Application to the Battersea Power Station of Researches into the Elimination of Noxious Constituents from Flue Gases and the Treatment of the Resulting Effluents." Hewson, Pearce, Pollitt, and Rees. Paper given at 52nd Annual Meeting of the Society of Chemical Industry, Newcastle, July, 1933.

Yet a further source of concentration exists. If the weak acid condensate is allowed to run on to hot surfaces, evaporation will take place, but instead of the SO_3 being expelled (as would be the case with SO_3), concentration would occur, and it would be possible to reach sulphuric acid of considerable strength. In certain cases metallic sulphates are formed, dehydrated, and subsequently heated sufficiently strongly *in situ* to expel sulphuric acid, giving rise to very severe conditions of attack.

It will therefore be seen that in dealing with corrosion by sulphuric acid we may have to consider a whole range of concentrations, from very weak solutions to the concentrated acids, even though the concentration of SO_3 in the original flue gases may be quite small. In passing, it may be noted that there is ample experimental evidence that the rate of attack is not necessarily proportional to the concentration of the acid. It is difficult to obtain information as to the relative proportions in which SO_2 and SO_3 are formed during the combustion of town gas.

It should not be overlooked that the sulphur acids are not the only corroding agents produced during combustion. In the case of iron appliances the carbon dioxide and water alone may prove very effective in causing corrosion if the temperature falls sufficiently for condensation to take place.

Then, again, oxides of nitrogen are produced during combustion, as has been clearly demonstrated in the 28th Report of the Joint Research Committee, 1931, and the amount of NO formed is of the same order as the typical sulphur figure, namely, about 0·01 per cent. by volume in the air-free products.

The NO is not itself a corroding agent, but in the presence of excess oxygen and water vapour gives rise to a mixture of nitrous and nitric acids. This is important in several respects. We have little or no control over the amount of nitric oxide, since this is a product of combustion, and cannot be reduced in amount by any scheme of purification of the gas, as is possible with sulphur. The nitrous and nitric acids will have specific corrosive properties of their own, believed to be quite marked in the case of the attack of copper, and the mixture of dilute nitric and sulphuric acids may prove a more vigorous corroding agent than either acid alone. The Institution of Automobile Engineers is investigating the relative importance of sulphur compounds and nitric oxide in relation to the wear of motor-car cylinder walls.

The oxides of nitrogen are also important in so far that they act catalytically and promote the oxidation of SO_2 to SO_3 and so alter the character of the corroding agent in the flue gases. They may also encourage the conversion of the dissolved SO_2 into sulphuric acid, thus enabling the condensate to take into solution further quantities of SO_2 from the flue gases, and so achieve higher concentrations even though the sulphur were mainly present as SO_2 in the flue gases. Similar increase in the amount of sulphur in solution could arise if that already in solution became fixed as metallic sulphites, with or without conversion to sulphate.

For many years gas undertakings have endeavoured to reduce the amount of sulphur in town's gas. Processes such as that of the South Metropolitan Gas Company, and the removal of benzol, whether by oil washing or activated carbon, simultaneously reduce the amount of sulphur left in the gas.

In many quarters it is believed that sulphur removal will completely eliminate corrosion difficulties with gas-burning appliances. It is obvious that improvement must result, but as has already been indicated, the problem is a complex one; the sulphur compounds are not the only corroding agents, and it therefore becomes desirable to investigate experimentally the degree of purification which is economically sound, so far as the corrosion aspect of the problem is concerned.

The first step would seem to be that of gaining some idea of the nature and extent of the attack under prevailing conditions of use. Although the subject must have attracted attention, there are surprisingly few published papers dealing with corrosion of gas appliances by products of combustion. The matter received attention in the Second Report of the Gas Heating Research Committee,[4] although hygienic conditions rather than corrosion were there under discussion. From an extensive series of observations with a typical condensing stove, E. W. Smith reported an average water-condensation of 12—13 c.c. of water per cu.ft. of gas burned, with a sulphur removal corresponding with 2·7—4·8 gr. per 100 cu.ft. of gas. As the sulphur content of the gas used ranged from 10·5—13·0 gr. per 100 cu.ft., this represented a retention in the condensate of about 80 per cent. of the sulphur. It was also noted that the condensate contained the equivalent of 5·2—8·7 gr. of iron per 100 cu.ft of gas burned, an amount of iron which is distinctly in excess of that required to form either simple ferrous or ferric sulphates. The figures probably underestimate the corrosion, for while the iron in the condensate (some of which precipitated in the collecting tray on standing) was completely accounted for, insoluble deposits inside the heater were neglected.

In 1924, U. R. Evans published a paper entitled "The Corrosion caused by Products of Combustion of Coal Gas,"[5] describing the appearance of corrosion deposits upon two gas-steam radiators, and the influence of the products of combustion upon metallic objects in the room in which they were burning. Unfortunately, quantitative data are not given, and no theories either as to the cause of attack or prevention are advanced.

Occasional indirect references to corrosion appear in the various reports of the Joint Research Committee of The Institution of Gas Engineers and Leeds University, dealing with products of combustion. Thus, in the case of a flueless heater of the condensing type (19th Report, 1928, p. 21), burning about 8 cu.ft. of gas per hour, it was observed that the condensate contained about 25 per cent. of the sulphur in the gas burned, together with small amounts of copper, and iron in practically those proportions necessary for the formation of ferrous sulphate. The sulphur content of the gas was approximately double that of Smith's tests, being 23—24 gr. per 100 cu.ft., while the condensation was much smaller, being only 4—4·5 c.c. per cu.ft. In the same Report, p. 42, figures were given for the amount of condensate from a 2½-gallon geyser, ranging from 5—25 per cent. of the water produced by combustion, but determinations of its sulphur and copper content were not made.

In the Twenty-Eighth Report (1931) the corrosion of a calorimeter was examined. Approximately two-thirds of the sulphur was removed in the condensate which contained nearly 0·1 per cent. of copper when burning a gas containing 25—30 gr. of S per 100 cu.ft. Marked quantities of nitrates were also found in the condensate. Work with this particular calorimeter has been amplified in the present Report.

A further example of corrosion was cited in connection with the "Sigma" Recorder.[6] This is of interest because a hard ring consisting essentially of ferric sulphate, with a slight amount of free sulphuric acid, was formed in the upper part of the chimney, although the temperature there was apparently high enough to preclude condensation.

Although dealing with solid fuel rather than with gas, there is much relevant information upon corrosion by products of combustion in a monograph upon corrosion in power plants by Johnstone, the paper containing also a useful review of analytical methods.[7]

In the present investigation corrosion deposits and condensates from a number of typical gas appliances have been examined and chemical analyses made; full details of the operating conditions under which the deposits have accumulated were not in all cases known or well defined.

A second important phase of the investigation is that of determining the resistance of various materials to the corroding influence of products of combustion. The literature upon corrosion and the resistance of materials to attack of various kinds is most extensive, a valuable catalogue of this having been prepared by Vernon,[8] who

[4] Trans. Inst. Gas Eng., 1910, p. 183. "Condensing Stoves."
[5] J.S.C.I. (2), 1924, pp. 506 and 7, and Jour. Inst. Metals Abstracts, 1925 (1), 371, and Journal of Iron and Steel Institute Abstracts, 1924 (2), 458.
[6] 30th Report of the Joint Research Committee, 1932.
[7] H. F. Johnstone. "Corrosion of Power Plant Equipment by Flue Gas." Univ. of Illinois Bull. No. 228, 1931.
[8] "Bibliography of Corrosion." W. H. J. Vernon, 1928.

lists some 3800 papers published up to the end of the year 1927.

It would appear to be a mistake to speak of the resistance of a metal to corrosion as a specific property of the metal. The corrosion depends upon the active agent and the circumstances of its application, factors which may account for the very different values attributed to the same material by various workers using different types of corrosion test, and for the difficulty of reconciling and applying their results. Much fundamental work has been done[9] upon the corrosion of metals, but for technical purposes it would appear that one must still work empirically, making the corrosion test approximate as closely as possible in essentials to the particular conditions of use in which one is interested. In this connection, we have designed apparatus for subjecting tubes of various metals to the action of products of combustion under controlled and reproducible conditions.

The main problems are to determine the effects of altering the temperature so as to vary the amount of condensation on the metal, to ascertain the effects of varying the amount of sulphur in the gas burned, and to select materials offering the greatest resistance to corrosion, consistent, of course, with reasonable cost and ease in manufacture.

While coatings employed usually delay or reduce attack, they are not as yet sufficiently homogeneous and resistant to afford a permanent protection against corrosion.

[9] "Corrosion of Metals." U. R. Evans, 2nd Ed., 1926.

Liquor Effluents and Ammonia

[3rd Report of the Sub-Committee]

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The work of the Liquor Effluents Sub-Committee, now incorporated in the Liquor Effluents and Ammonia Sub-Committee, has been directed mainly towards facilitating the disposal of gas works waste liquors by recognized methods, although new processes of disposal have been tried. The most commonly used method of disposal, and one which has caused difficulties to arise in many places, is by treating the liquors in admixture with sewage at a sewage treatment works.

The Report gives an account of the first stage of a comprehensive investigation into the biochemical oxidation of gas works liquors. The general aim of the investigation is to ascertain the conditions and concentrations in which gas works liquors can be oxidized along with sewage by recognized methods, to study the effect of the type of liquor and its composition, to assess the additional burden, if any, placed on the purification plant by the presence of the liquors in the sewage, and to indicate the best methods of facilitating their treatment.

This Report describes the sectional and non-sectional bacteria beds and the laboratory activated sludge apparatus which have been used in the work, discusses the methods of testing employed, and points out the limitations to which these are subject.

So far as is known, the difficulty of treatment of gas works liquors is due to the presence in them of substances which have an oxygen absorption, reducing $KMnO_4$ in acid solution at 80° F. These substances are phenols, higher tar acids, thiosulphate and thiocyanate, in the case of spent liquors, and the same with the addition of sulphide in ammoniacal liquors. The oxidation of each of these substances in the presence of sewage has been studied.

Experiments on non-sectional filters shewed that all the substances could be destroyed completely by bacterial action. For these filters, under the conditions of operation, the limit of concentration in which complete oxidation occurred, was reached with thiosulphate at oxygen absorption (O/A) 16-32[1] and with sulphide at O/A 8-16. Phenol, thiocyanate and catechol (representing higher tar acids) were oxidized completely up to and including O/A 32, and later experiments shewed that thiocyanate could be destroyed even if fed to the bed in concentration O/A 100. This substance, however, could not be dealt with when first applied to the bed; evidently specialized bacteria must first be given an opportunity to develop.

With the sectional filters it was shewn that phenol of concentration O/A 4 was oxidized very rapidly, having disappeared completely long before the sewage with which it was mixed was purified to an extent which would normally be considered satisfactory. Catechol disappeared rather less rapidly, and thiocyanate more slowly still, even when the filters had become accustomed to it.

Experiments with activated sludge confirmed and extended these results, and the order of increasing difficulty of oxidation of the substances under consideration was shewn to be phenol, thiosulphate, catechol (higher tar acids), thiocyanate, and sulphide. The first two substances were completely oxidized in a time of aeration shorter than that required to purify the sewage to a satisfactory standard. Catechol lagged behind somewhat, and thiocyanate was oxidized hardly at all during the first four runs, after which, when the specialized bacteria had developed, it disappeared at a satisfactory rate, although never so rapidly as phenol and thiosulphate. Sulphide, besides being difficult to oxidize, had an adverse effect on the activated sludge.

The individual constituents of gas works liquors are not therefore all of the same importance, in so far as biochemical oxidation is concerned. For instance the preliminary removal of an O/A of, say, 200 due to thiocyanate would improve a liquor more than the removal of a corresponding quantity of phenol. Indeed, the removal of phenol alone would appear to be of very doubtful benefit. It would seem that a particularly suitable spent liquor for treatment in admixture with sewage would be that from a crude liquor originating in gas which, while still above the dew point is subjected to the action of an efficient tar precipitator, and which is kept free from oxygen until it enters the purifiers. Although such a liquor would have a high phenol content, it would be almost free from higher tar acids, thiocyanate, and thiosulphate. It would therefore be easily oxidized. The ammoniacal liquor from such a system would contain, in addition, sulphide, which is difficult to oxidize, but there is no simple method at present either of preventing its occurrence, or of removing it, except by distillation.

The above conclusions are, of course, tentative, and merely indicate the trend of the results of the part of the investigation which is reported. They are to be tested in an extension of the work which is now in progress.

The Report, on the removal of phenols from ammoniacal liquor by distillation, contains an account of a study of the relative rates of distillation of phenol and ammonia from dilute solutions. Both these substances distil from aqueous solutions in such a manner that the concentration of substance in the vapour is n (a constant) times that in the liquid. From n can be found the minimum quantity of steam required to remove completely these substances from water in a continuously operating high

[1] Oxygen absorptions (O/As) are expressed throughout this Report in pts O_2/100,000.

efficiency still. These quantities, and the values of n are:—

Substance.	n.	Minimum Steam Required.
		Per Cent.
Phenol	1·83	54·8
p-Cresol	2·75	36·4
m-Cresol	2·41	41·5
Ammonia	11·4	8·8

Ammonia is thus 6·2 times as volatile in steam as is phenol, and cresols shew a larger value of n than does ordinary phenol.

The presence of ammonia was found to retard the distillation of phenols, n being lowered until the ammonia had distilled off, and the presence of CO_2 (as ammonium bicarbonate) has a similar effect on the distillation of ammonia. Both these effects act in the same direction, and it can be anticipated that the relative rates of phenol and ammonia removal from gas works liquor will be but little different from the rates of distillation from water. This has been confirmed with an ammoniacal liquor using a Young fractionating column as a continuously operating still.

One cannot hope therefore to remove more than a comparatively small quantity of phenol when liquor is distilled to remove ammonia in the most economical manner. The complete removal of phenol would require a much greater quantity of steam. Nevertheless, this process is being operated at a coke oven works in the U.S.A., the aim being to separate the toxic (phenols) from the corrosive (ammonium chloride) constituents of crude liquor. The claim made, however, that phenol removal is nearly identical with that of free ammonia does not seem to be borne out in these experiments.

Ammonia.

The Report describes a method, which has been patented by the Institution, of manufacturing ammonium bicarbonate from crude vertical retort coal gas. This compound is considered a possible alternative to ammonium sulphate as a fertilizer, the chief advantage over the latter salt being that sulphuric acid is not needed for its preparation. This, other things being equal, would mean a considerable economy in ammonia recovery.

The theoretical aspect of the formation of the salt is discussed, and it is concluded that, in order to render possible the deposition of ammonium bicarbonate from crude coal gas, it is necessary either to cool the gas to temperatures much below normal, or to increase either its carbon dioxide or its ammonia content. The latter alternative forms the basis of the process, and the method by which it is effected is to concentrate the ammonia from the whole of the gas into a fraction of it.

Briefly, the process consists of dividing the gas stream at the outlet of the condensers, efficiently de-tarring the fraction to be used in the process, enriching it with ammonia (containing an equivalent amount of water vapour) by distilling into it the ammoniacal liquor produced from the whole of the gas, and passing the mixture through a vessel containing a solution saturated with ammonium bicarbonate. After leaving this absorption vessel the gas, after a preliminary washing, will rejoin the main gas stream before this reaches the scrubbers. The fraction of the gas and the amount of ammonia used in its enrichment will be chosen so that both ammonia and carbon dioxide will be absorbed, ultimately in equal volumes, by the solution in the absorption vessel. This will then become supersaturated with ammonium bicarbonate, of which an amount equivalent to the ammonia absorbed from the gas will be deposited as crystals, which will be separated and dried, and the solution used again in the absorber.

Laboratory experiments shewed that the efficiency of the process depended largely on the CO_2 content of the gas. With a small absorber filled with glass rings and giving a time of contact of 12 seconds, 49 per cent. of the ammonia was absorbed from a gas containing 5·6 per cent. CO_2 and 1400 gr./100 cu.ft. ammonia, and 28 per cent. from a gas containing the same amount of ammonia and 3·7 per cent. CO_2.

On a small scale plant treating 100 cu.ft. of crude coal gas per hour higher efficiencies were obtained, due principally to a lower temperature of washing.

Further consideration of the process indicated that there should be a minimum carbon dioxide content of the gas leaving the absorber, below which not bicarbonate but a mixture of this salt and ammonium carbonate would separate out. This minimum has been found to be of the order of 1·3 per cent. To be on the right side, however, a value of 1·5 per cent. has been used for calculating the smallest fraction of gas necessary for the process for gases of various CO_2 contents. These are as follows:

Per Cent. CO_2 in Purified Gas.		Fraction of Total Gas Required.
5·25	..	1/12
4·25	..	1/9
3·25	..	1/6
2·25	..	1/3
1·75	..	2/3
1·60	..	1

Thus the gas which marks the limit of application of the process is one which when purified has a CO_2 content of 1·6 per cent.

The questions of the distillation of the liquor and the possible impurities in the ammonium bicarbonate produced are briefly discussed.

Report on the Accident at Neunkirchen (Saar) Involving a Waterless Gasholder

[2nd Report of the Gasholder Sub-Committee]

The gasholder involved was of the M.A.N. waterless type, and it had been in operation since August, 1931, at the Neunkirchener Eisenwerke A.G., Neunkirchen, Saar. The accident occurred on the 10th February, 1933, at 6 p.m.

The holder had a capacity of 4,250,000 cu.ft., and was 160 ft. in diameter and 235 ft. high. It was the only storage holder of the coke oven plant at the steelworks, which were located at the eastern side of the town of Neunkirchen and constituted the principal business of the town. The holder was completely wrecked by the explosion, and some 68 people lost their lives and about 100 persons were injured.

Representatives from the Gas Light and Coke Company and the South Metropolitan Gas Company visited Neunkirchen on the 16th and 17th February, 1933, respectively. The Sub-Committee has examined the two reports made as a result of these visits.

On 16th to 18th March, 1933, Mr. C. S. Shapley, Engineer and Manager, City of Leeds Gas Department, visited the site and made investigations on behalf of the Sub-Committee. The Sub-Committee has considered his report, together with the report of the two representatives of the Gas Light and Coke Company—Mr. F. M. Birks and Mr. E. J. Hutchence—who accompanied him.

Conclusions.

We are of opinion that if the precautions normally taken in this country during repairs to mains had been observed the disaster would not have taken place.

It is considered that no one would have foreseen that an explosion in the by-pass main was likely to bring in its trail so disastrous a result, and it was indeed an ill chance that the one effect of the first explosion was to damage the outlet main at the only point at which so serious and unforeseen an accident could have resulted.

The accident specially emphasizes the importance of:—

(*a*) Having the connections to and from waterless gasholders of substantial construction, and holders as far away as possible from the effects of any outside fire.

(*b*) Excluding the use of oxy-acetylene and other flames in connection with repairs to mains or plant which have not been totally isolated from live gas plant and purged from gas.

THE MORE IMPORTANT PRECAUTIONS TAKEN BY GAS UNDERTAKINGS OPERATING WATERLESS GASHOLDERS.

1. The provision of a system of inspection to ensure that the piston is operated in accordance with design and that the seal is efficiently maintained.
2. The provision of means for the removal of any disabled man from the top of the piston.
3. The provision of a spare man on the top of the holder when anyone enters the upper part of the holder and during the period that anyone is within this part.
4. No lights of any kind except safety lamps of a pattern approved by the Home Office for Use in Fiery Mines are allowed above the piston and no electric apparatus installed there.
5. A continuous record is kept of:—
   a. The level of the piston,
   b. Pressure conditions.
   c. The number of pump runs.
6. The provision of a duplicate and independent electric supply to the pumps and a method of warning should either source of current fail.
7. Inflammable or corrosive materials are not allowed near the holder.
8. Naked lights are not allowed in the vicinity of the holder.
9. Matches and lighters are not allowed to be in the possession of anyone ascending the holder.
10. Nailed footwear is not allowed to be worn by anyone inside the holder.
11. Precautions are taken to prevent any unauthorized person ascending the holder.
12. Valve chambers, as far as possible, are filled in solid with earth or sand.

Leakage in Horizontal Retorts

By A. H. CLUCAS, M.Sc., A.I.C., City of Leeds Gas Department

ESTIMATION OF COAL GAS LEAKAGE BY ANALYSIS OF THE WASTE GASES.

In this section there is discussed the method of estimating the leakage of coal gas through the retort walls by the determination of the depression of the content of carbon dioxide in the waste gases below that in the theoretical products of combustion of producer gas.

EXPERIMENTAL RESULTS.

Normal Working Conditions.

Results of nine tests are given in Table I. Each test was carried out on an individual bed of retorts for a period

TABLE I.—*Coal Gas Leakage from Horizontal Retorts—Normal Working Conditions.*

Test No.	Bed.	Working Life of Retorts. Carbonizing Days.	Per Cent. CO_2 in Combustion Products (Air-Free).		Depression.	Equivalent Leakage Per Ton of Coal Carbonized. Therms.
			Producer Gas. (*a*)	Waste Gases. (*c*)	(*a* − *c*)	
1	2	3	4	5	6	7
1	A	2500	20·51	20·38	0·13	0·7
2	,,	,,	20·52	20·30	0·22	1·2
3	,,	2700	20·48	20·13	0·35	2·0
4	B	2500	20·45	19·98	0·47	2·7
5	,,	2650	20·58	20·37	0·21	1·1
6	C	1900	20·57	20·23	0·34	1·9
7	,,	,,	20·42	20·12	0·30	1·7
8	D	1570	20·30	19·98	0·32	1·9
9	,,	1620	20·47	20·07	0·40	2·3

of about ten hours. The working lives of the retorts at the times of testing varied between 1570 and 2700 working days for the different beds and no retort had been scurfed within twenty days prior to testing.

Leakage of coal gas was indicated in every case by this method of testing and varied between 2·7 and 0·7 therms per ton of coal carbonized. It is not possible, however, to correlate the amount of leakage found with the working lives of the retorts.

The pressures at the middle line of retort mouthpieces varied between + 0·2 and + 0·05 in. w.g. during each of these tests.

Effect of Excessive Pressure Conditions.

In Tests 1 to 9 the pressure at the middle line of retort mouthpieces did not exceed + 0·05 in. w.g., and in order to detect the effect of excessive pressure conditions within the retorts upon the extent of leakage, an experiment, Test 10, was carried out as follows:—

i. Bed working under normal conditions for a period of five hours.
ii. The anti-dip pipes of every retort were sealed on one side of the bed only and maintained in that condition for three hours.
iii. The anti-dip pipes at both sides of every retort were then sealed, these conditions prevailed for two hours.
iv. The anti-dip pipes were unsealed at both sides, and normal conditions prevailed for a final period of two hours.

During each part of the experiment a series of spot samples of waste gas, and one continuous sample of producer gas were obtained. In all, seventy-two waste gas and four producer gas samples were taken during the test.

The results have been summarized in Table II. The

TABLE II.—*Test 10.—Effect of Excessive Pressure Conditions*

Carbon Dioxide in Waste Gases After Complete Combustion. (Air-Free, Dry.)	Carbon Dioxide in Theoretical Combustion Products of Producer Gas. (Air-Free, Dry.)	Depression.	Equivalent Leakage per Ton of Coal Carbonized.	Average Pressure Conditions at Retort Mouthpieces.
Per Cent.	Per Cent.	(*a* − *c*).	Therms.	(Inches w g.).
1	2	3	4	5
Normal conditions.				
20·18	20·38	0·20	1·1	0·05
Anti-dip pipes sealed on one side only.				
19·65	20·24	0·59	3·6	Not known
Anti-dip pipes sealed on both sides.				
18·68	20·22	1·54	11·1	About 1
Normal conditions.				
20·19	20·23	0·04	0·5	0·03

results indicate that with normal conditions the leakage of coal gas was of the same order as that obtained in all previous tests having similar working conditions.

A leakage of about 3·6 therms occurred when all the anti-dips on one side were sealed. This result was unexpected, and can only be explained by the development of excessive pressures within one or more of the retorts. No facilities were available at the time for measuring the pres-

sures simultaneously at each mouthpiece, but measurements made on later occasions have indicated the possibility of the development of excessive pressures, although only one dip pipe of a retort is sealed. It may be that when this occurs the retort is packed with coal in the middle portion of its length, thereby offering a resistance to the passage of gas to the open ascension pipe, and thus creating excessive pressures at one end.

Sealing the dips at both sides gave a pressure of about one-inch w.g. at the retort mouthpieces, and it is believed that serious leakage of coal gas of the order of 15 per cent. occurred under these conditions.

It is interesting to note that when this pressure was removed, the carbon dioxide content assumed its normal value.

Test 11.—*Effect of Newly Scurfed Retorts on Leakage.*

In Tests 1 to 10 the full complements of retorts in the respective beds were in use. In addition, the times of testing were selected so that no retort had been scurfed within twenty days prior to testing.

TABLE III.—*Test 11.—Effect of Newly Scurfed Retorts on Leakage.*

Sampling Periods.	Carbon Dioxide in Waste Gases after Complete Combustion. (Air-Free, Dry).	Carbon Dioxide in Theoretical Combustion Products of Producer Gas. (Air-Free, Dry).	Depression.	Equivalent Leakage Per Ton of Coal Carbonized.
Hours.	Per Cent.	Per Cent.	(*a* − *c*).	Therms.
1	2	3	4	5
Before charging scurfed retorts, Period of Survey = 4 hours.				
0–2	20·35			
2–4	20·47			
	Average 20·41	20·52	0·11	0·6
After charging scurfed retorts, Period of Survey = 7 hours.				
0–1 (Five 12 min. samples)	20·25 20·26 19·99 19·11 19·76			
1–2	19·76			
2–3	19·86			
3–4	19·90			
4–5	19·86			
5–7	19·88			
	Average 19·86 (weighted)	20·50	0·64	3·8

Test 11, however, was conducted with a view to detecting the influence of newly scurfed retorts on the extent of the gas leakage. The normal practice is to allow only one retort at a time in any one bed to be taken off for scurfing. In order to intensify any leakage effect it was arranged that four retorts in one bed were scurfed at the same time. The results are given in Table III., and show that for the four hours preceding the charging of the scurfed retorts, the depression of the carbon dioxide in the waste gases was only 0·1 per cent., too small a quantity to be interpreted with certainty as leakage. It should be pointed out that only four retorts were working, but the volume of waste gases passing through the bed was the normal amount for eight retorts.

The four scurfed retorts were charged quickly one after the other and a depression of the carbon dioxide soon appeared and varied only slightly for the seven hours under survey. The average depression was 0·64 per cent., equivalent to a coal gas leakage of at least 5 per cent. from the bed as a whole. It is reasonable to assume that the major portion of this leakage was from the four scurfed retorts, so that actually the leakage of coal gas from these particular retorts was of the order of 10 per cent.

The pressure conditions during the test averaged + 0·03 in. w.g. at the middle line of retort mouthpieces; an increase of about + 0·03 in. w.g. was noted throughout the first hour after the scurfed retorts had been charged.

Determination of the Leaky Condition of Retorts by Direct Measurement.

The method adopted is based on the procedure indicated by T. F. E. Rhead, where cooled waste gases are pumped into a sealed empty retort and the leakage through the retort walls determined by measuring the rate of delivery and the pressure maintained within the retort. It is recognized that waste gases are very suitable, but local difficulties prevented their use and air was selected for the experiments. An apparent objection to the use of air when testing retorts covered with scurf is that it might bare a portion of the retort surface, but special experiments have shewn that the amount of air used for a test was not likely to thin the scurf sufficiently to give false leakage figures.

The method is simple, and does not call for elaborate apparatus or precise gas volume measurements. Great accuracy is not claimed, but it is considered sufficient for the purpose in hand and enables similar retorts to be compared.

Method of Expressing Results.

The leakage results were found to approximate to a straight line function of pressure, and have been expressed in terms of a Leakage Index; thus:—

$$\text{Leakage Index} = \left\{ \begin{array}{l} \text{Leakage in cubic feet (at 60° F.) per hour for} \\ \text{every one-hundredth inch w.g. pressure} \\ \text{exerted within the retort.} \end{array} \right.$$

The Leakage Index represents the condition of the complete retort, including the mouthpieces and the joints between these and the retort sections.

Interpretation of Results.

The main object of this method of leakage determination was to compare retorts working under normal conditions in different parts of the retort house, and also to survey the effect of scurfing and the tightening effects of hot patching, wet spraying, and scurf formation. Useful comparisons between cold retorts undergoing repairs have also been made.

The order of the thermal leakage equivalent to the Leakage Index is illustrated by the following example, but it should be emphasized that no claim is made that such equivalents can be calculated with any great precision.

Example—For one bed of eight retorts making 5360 cu.ft. crude coal gas per hour.
Assume average pressure conditions within retort = 4-hundredths inch (w.g.).
Assume average Leakage Index = 2.
Then $(8 \times 4 \times 2) \div 53{\cdot}6 = 1{\cdot}2$ per cent. volume loss, or about 0·8 therm per ton of coal carbonized.

Experimental Results.

Normal Working Conditions.

Various retorts were selected at random in different parts of the retort house and tested for leakage by the air method. The results for seventy-five retorts are summarized below:—

Leakage Index.

1 and less	37 retorts
Between 2 and 1	28 ,,
Between 3 and 2	5 ,,
Greater than 3	6 ,,

Sixty-five of the retorts have leakage values of 2 or less, and it would appear that this range represents normal working conditions. No evidence was obtained that the leakage was influenced by the working life of the retort (1500 days being the minimum period under consideration) or by the position it occupied in the setting.

Five of the six retorts which gave results greater than 3 had not more than five days' accumulation of scurf when tested. The scurf covering on all other retorts had accumulated during periods ranging between sixteen and two hundred days for the different retorts, but the results did not indicate any relationship between this period and the Leakage Index.

The Effects of Scurf, Hot Patching, and Wet Spraying.

A considerable number of hot retorts have been tested to determine the effect of scurfing, and also the tightening produced by hot patching, wet spraying, and scurf formation. The results obtained are considered below.

(*a*) *The Effect of Scurfing.*

The Leakage Index immediately before scurfing varied between 1 and 3. When the scurf had been removed, and

even after the normal hot-patching repair work, the results shewed a very great increase in the Leakage Index. The extent of this increase differed considerably for the different retorts, and varied between forty and one hundred and fifty times the value before scurfing.

Tests have shewn that the mouthpiece joints were rarely responsible for any large portion of the leakage existing after scurfing.

(*b*) *The Tightening Effect of Hot Patching.*

The normal practice is to carry out hot-patching repair work on every retort after scurfing. It was found that this operation seldom reduced the Leakage Index by more than about 25 per cent.; further, very extensive hot patching gave only a slight additional improvement.

(*c*) *The Tightening Effect of Spraying.*

When the working life of any retort reaches 1200 days it is the routine practice, after scurfing and in addition to hot patching, to spray it with a refractory slip.

The tightening produced by this operation was disappointing. Generally, it was even less than that obtained by hot patching and in some cases there was no lowering of the Leakage Index.

An experiment was carried out to determine the effect of four successive spraying operations at hourly intervals on an individual retort. The Leakage Index before scurfing was < 1, after scurfing and hot patching it increased to 40, the first spraying operation reduced the value to 35, but no measurable reduction was obtained by the three additional sprayings. It is estimated that altogether about 200 lbs. (dry basis) of refractory cement had been sprayed into the retort during the four operations.

(*d*) *The Tightening Effect of Scurf Formation.*

It has been shewn that retorts were found to be relatively gas-tight when coated with the maximum amount of scurf collected during normal working; this maximum formation represented an accumulation during anything from eighty to two hundred days. Scurfing the retorts produced a condition that allowed considerable leakage to take place, and even after hot patching and spraying they leaked extensively. It was very desirable to know the carbonizing period necessary to form sufficient scurf to effect a tightness equivalent to that existing immediately before scurfing.

After carbonizing for one day an appreciable reduction in the Leakage Index was obtained, the scurf produced being sufficient to reduce the figure to between one-third and one-fifth that existing before the first coal charge. A marked improvement was obtained after the first day and, in most cases, a period of three to five carbonizing days reduced the leakage to a value only about double that existing before scurfing.

Surveys of complete "scurfing-to-scurfing" periods shewed that generally the Leakage Index did not alter to any great extent after the first six to ten days. In a few cases, however, a greater variation was obtained.

THE INFLUENCE OF SCURF FORMATION.

The benefits of scurf formation are well known, and, in the case of horizontal retorts that had worked at least 1500 days, it has been demonstrated by experimental results that the scurf layer was the major factor in making them gas-tight. The removal of this scurf made it possible for considerable leakage to occur and at least five carbonizing days were necessary, with a newly scurfed retort, to reduce leakage to the same order as that existing before scurfing. During one carbonizing day, however, sufficient scurf was formed to exert an appreciable tightening effect which was usually greater than the combined effect of hot patching and spraying.

A very thin layer on parts of a retort surface was often observed at the end of a single carbonizing period after scurfing, but at least ten days was required to form a layer that had the appearance of completely covering the retort surface.

No doubt, a large portion of the deposition of scurf during the first few carbonizing days takes place within the cracks. The demolition of old retorts, however, has shewn holes and cracks of such dimensions that it is difficult to imagine any effective sealing by the deposition of carbon within them. In such cases effective tightening was probably dependent on the formation of scurf layers over the openings.

The Amount of Scurf formed.

The weight of scurf removed during one scurfing operation varied between 2·5 and 3 cwt. for a single retort. It is thought that not more than about 10 per cent. was burnt away during the scurfing process. The time taken to accumulate this amount varied somewhat for individual retorts in similar positions in the respective beds. The periods given below are the averages of observations on 200 retorts during two years.

Retort Position in Setting.	Period Between Consecutive Scurfing Operations.
Centre top and middle*	12 weeks
Left and right top	18 ,,
Left and right middle	20 ,,
Left and right bottom	30 ,,

* The centre top and middle retorts carbonize eight hour charges; all the other retorts carbonize twelve hour charges.

The average daily production of scurf at the maximum rate of formation (*i.e.*, 3 cwt. in twelve weeks) is 4 lbs., equivalent to a layer only 0·004 inch thick if distributed uniformly over the retort surface. However the deposition of scurf is not of uniform thickness over the whole surface of any retort; in addition, the rate of accumulation is probably greater during the first few carbonizing days after scurfing, and some is deposited in cracks. These factors make it impossible to estimate the amount and thickness of the scurf layer which causes a retort to be relatively gas-tight. It is apparent, however, that such quantities are very small.

The Thermal Value of Scurf.

The average amount of scurf formed in a single bed during twelve months working was about 60 cwt. The coal carbonized during that period was 3440 tons, and, thus the scurf formation was equivalent to about 0·28 therms per ton of coal carbonized. Degradation of tar produces some of the scurf, so the actual loss of gaseous therms was something less than 0·4 per cent.

Nature of Scurf Formation.

The texture of scurf in different parts of a retort varied considerably. In the lower parts it had a very dense structure and became less dense towards the crown.

SPRAYING OF FIRECLAY RETORTS.

When spraying was first introduced at the New Wortley Works, very little information as to the most satisfactory methods for carrying out the process was available, and no beneficial results could with certainty be predicted; its adoption was therefore essentially experimental. It was hoped, however, that one of the chief advantages would be to prevent loss of gas by leakage through the retort walls, but the results of the various leakage tests were disappointing in this respect, and no evidence was obtained that spraying produced any appreciable tightening of the retorts.

Benefits were, however, obtained in quite an unexpected direction and are described below. It was known from experience that, after working about 1200 days, the retorts began to give trouble during discharging, particularly in the case of newly-scurfed retorts. These conditions became worse with age, and in course of time it was often necessary to remove some portion of the charge by hand, thus requiring extra labour and adding to the cost of gas production. This difficulty in discharging retorts was an important factor influencing the management in any consideration to let down the plant for either cold repair or rebuilding.

The spraying of these retorts coincided with a pronounced reduction in discharging troubles, and an attempt was made to ascertain if this could be attributed to the spraying. Observations were therefore made on twelve pairs of retorts, one only of each pair being sprayed. Experiments of this type do not lend themselves to quantitative expression, and caution is necessary in interpreting results of observations on only a

limited number of retorts. However, the relative values of " discharging difficulties " for the retorts examined, indicated a definite advantage to be obtained by spraying. It was not convenient to extend these experiments, but later experience over two years, compared with that of previous years, confirmed these results. It is evident that spraying gives definitely beneficial results in that it reduces discharging difficulties with old retorts, and that it is a factor contributing to the attainment of a longer working life.

No certain explanation can be offered for this easing of discharging difficulties, and it must be a matter of some conjecture. The shapes of these old retorts were, generally, very good but the inner surfaces had innumerable cracks of varying sizes. If the coke became moulded into these cracks, and particularly at the bottom of the retort, it would offer considerable resistance to the discharging ram. Although spraying did not fill up these cracks completely, it did reduce their depth and irregularity, and thus the extent of any " keying in " of the coke. In addition, it has been estimated that at least one quarter of the cement sprayed into a retort collected on the bottom as a loose powder; this apparent waste may actually have been the main factor in giving the beneficial results; the powder acting as a solid lubricant.

Composition of Spraying Medium.

The spraying medium consisted of a slip containing about five pounds of refractory cement to one gallon of water. Any cement in excess of this amount gave trouble due to blockages in the spray pipe. The cement was purchased ready for use and analysis showed it to be mainly a siliceous material with a high lime content.

Quantity of Spraying Medium used for one Retort.

The quantity of spraying medium used for one retort varied between about 100 lbs. and 200 lbs. of slip. The average of a series of determinations was 170 lbs. containing about 60 lbs. cement and 11 gallons water, and the time taken to deliver this amount was 20 minutes.

Deposition of Refractory Cement on Retort Surface.

The 60 lbs. of refractory cement introduced into a retort during the spraying operation would give, if uniformly distributed, a layer only about 0·04 in. thick. Actually, about one quarter did not adhere to the surface, but collected at the bottom as a loose powder. Prior to the demolition of some old retorts, and after their last carbonizing period, the opportunity was taken to scurf and spray them before letting down. Inspection when cold shewed that the refractory cement other than that loosely collected in the bottoms was fairly uniformly distributed over the whole surface of the retorts. No vitrification or strong adhesion was noted, the layer being very friable and easily removed.

In view of the friable nature of the cement layer it was desirable to ascertain whether, or not, it was removed during the first few discharging operations after spraying. Examination during the demolition of retorts covered with scurf, has shewn layers of cement clearly defined under the scurf and in many places it had hardened and attached itself firmly to the retort face. It was noted also that the effect of spraying may be cumulative, two or more distinct layers of cement being observed in some portions of the retorts.

The Cooling of the Retort Surface.

It is recognized that the extent of surface cooling allowed to occur with the retorts at New Wortley works was excessive. It was only countenanced because of the ages of the retorts, the least being 1500 working days. The retort surfaces were all badly cracked prior to the introduction of spraying, and no evidence was obtained that such conditions were intensified by this drastic spraying process.

The practice of spraying retorts when new and at any time before they have worked about 1200 days, has been given consideration, and it is apparent that considerable modification in the spraying process would be necessary. Even then, there is some uncertainty as to the resulting benefits prior to the time when the retorts commence to give discharging troubles.

Refractory Materials

[24th Report of the Joint Sub-Committee]

In the Twenty-Third Report of the Refractory Materials Joint Sub-Committee mention was made of the fact that as a result of the appeal for funds for the work of the British Refractories Research Association which was made to manufacturers and users during the summer of 1932, materially larger resources were available, which, it was expected, would permit of considerable enlargement of the programme of research to be carried out, both in respect of general fundamental matters, and in subjects relating more particularly to special industries.

This expectation has been fulfilled and with increased revenue it has been possible to increase the number of research workers and to add to the equipment of the Laboratories at Stoke-on-Trent. The extent of the work carried out, both in general matters and in special problems of more particular interest to one or other of the subscribing industries has accordingly been materially increased. In view of the fact that, of necessity, some little time was occupied in bringing the new arrangements into working order during the earlier part of the period, it is confidently expected that the extent of work carried out during the coming year will be still further increased.

In view of the increased contributions made by the different industries, and especially by the Gas Industry, alterations have been made to the constitution of the Council of the British Refractories Research Association to give more effective representation to the various industries. The representation of the Gas Industry on the Council is now as follows: two members of the Council are nominated by The Institution of Gas Engineers, and one member each by The Gas Light and Coke Company and The South Metropolitan Gas Company; in addition, two members are nominated on behalf of the other Gas Undertakings subscribing to the funds.

In order further to increase the intimate working of the British Refractories Research Association with the different industries concerned, a number of Joint Committees of the former with bodies representing individual industries has been formed. So far as the Gas Industry is concerned, the Refractory Materials Joint Sub-Committee has, ever since the formation of the British Refractories Research Association in 1921, acted as the connecting link, but in order to render this more effective and to bring matters into line with other industries, this Joint Sub-Committee has during the past year been reconstructed as " The Refractory Materials Joint Sub-Committee of The Institution of Gas Engineers, the Society of British Gas Industries, and the British Refractories Research Association." Five of its members are nominated by the Institution, five by the Society of British Gas Industries, and two by the Council of the British Refractories Research Association. In addition the President and Honorary Secretary of the Institution and the Director and Assistant Director of the British Refractories Research Association are *ex-officio* members of the Sub-Committee.

Consideration has been given to the " Standard Specification for Refractory Materials for Gas Works " published by the Institution, the last edition of which, issued in 1925, is now out of print. It was decided that a considerable revision of the Specification was now due, and a special sub-committee was appointed, which has drafted a re-

vised Specification; this will shortly be considered by the full Refractory Materials Joint Sub-Committee, representing manufacturers and users.

Work Carried out by the British Refractories Research Association.

The Hot-Patching of Gas Retorts—Use of Dry Powdered Cements Containing Silicon and Aluminium.

By F. H. Clews, M.Sc., A.I.C., H. Booth, and A. T. Green, F.I.C., F.Inst.P.

The results obtained in the laboratory with mixtures of fine aluminium powder and finely crushed silica brick or ganister are in the opinion of the authors sufficiently encouraging to merit the trial on a larger scale of the mixture as a hot-patching material for gas retorts. One direction in which some improvement would be a decided advantage is in the nature of the surface left at the conclusion of the process of cementing. This is not so smooth as is obtained by the use of wet plastic cements. However, modifications in the design of the burner might be introduced to remedy this defect. Another difficulty arises if the attempt is made to project the cement powder upwards, as a much greater air velocity will be required to carry the powder forward without separation of the constituents. It appears for this reason that repairs to vertical retorts would be more effectively carried out from the top than the bottom. It also seems more than likely that water cooling of the cement burner and its connections will have to be provided for. However, trials on a larger scale only can decide whether the repairs effected by this material and process are sufficiently superior to those now employed and outweigh the disadvantages involved in the use of the necessarily somewhat complicated mechanical equipment required.

Grading, Porosity, and Permeability to Air of Silica Bricks.

By F. H. Clews, M.Sc., A.I.C., and A. T. Green, F.I.C., F.Inst.P.

Based on the results of preliminary experiments on the packing densities of mixtures of different grades of ground ganister, silica brick batches have been prepared which might be expected to give fired products of approximately minimum porosity and permeability. Three different classes of specimens, described as coarse, medium, and fine-grained, have been prepared, using making pressures of $2\frac{1}{4}$, $4\frac{1}{2}$, and $6\frac{3}{4}$ tons per sq. in. A number of hand-tamped specimens have also been made.

The making pressure has been found to affect the values of the permeability to air considerably, products of permeability in the region of 0·04 being obtained at the highest pressure used. Nevertheless, the specimens made at the considerable pressure of $2\frac{1}{4}$ tons per sq. in. were not markedly less permeable than those of the same grading made by hand.

The effect of the making pressure on the observed apparent porosity was, in comparison with the effect on the permeability, less marked.

A further instance has been obtained of the effect on the properties of the fired bricks of the distribution of sizes in the ganister classed as fine.

Coarse and medium grained products of low and almost equal permeability have been obtained, but with a difference in apparent porosity of about 4 per cent.

The effect of the addition of $\frac{1}{2}$ per cent. cellulose liquor tends to produce a product of slightly lower permeability.

The Action of Alkalies on Refractory Materials.

By F. H. Clews, M.Sc., A.I.C., A. Green, and A. T. Green, F.I.C., F.Inst.P.

A general review of the problems associated with the behaviour of refractory materials towards alkalies is given in the Bulletin B.R.R.A., No. 30, which emphasizes the complexity and many sided nature of the subject. It is shewn for example that deterioration and disintegration of refractory materials can occur by chemical and physical actions taking place between alkali compounds in the solid, liquid, and gaseous states.

An examination of the brickwork of continuous vertical retorts let down for repairs or dismantling has furnished fairly definite evidence of the attack on the refractories of alkalies in the liquid and gaseous condition.

It would appear that direct transfer to the walls of the inorganic constituents of the coal during the passage of the charge down the retort does not occur to any appreciable extent until the bottom of the retort is being approached, where steaming by consumption of a portion of the carbon of the coke assists in the liberation of the incombustible constituents. We thus find pronounced slag formation in the lower portion of the retort, the composition of which is in keeping with the analysis of the coal ash. Higher up in the retort, surface glazing is diminished, but the coking surface of the refractories is none the less found to be contaminated by alkalies which may constitute as much as 50 per cent. of the added matter, even when the amount present in the coal ash is under 10 per cent. The conclusion naturally follows that it is mainly in the state of vapour that the alkalies have reacted with the brickwork in the upper half of the retort. In this condition there is greater opportunity for penetration into the pores of the refractory material, more particularly when, as is usually the case, there is an excess of pressure within the retort over that existing in the flues, and the actual vapour pressure of the alkalies is small. It is not likely, however, that the contaminated zone would extend much beyond the coking face in view of (1) the small proportion of alkali in the penetrating gases, (2) the small value of the excess pressure in the retort, and (3) the readiness with which the reaction occurs at the usual temperatures predominating, the rate of which increases as the alkalies pass in the direction of the heating flues. The alkali contamination observed in the surface layers cannot but tend to produce weakness by the destruction or modification of the structure of the original material, an effect which will be all the more severe the more localized and concentrated are the new structural modifications. The new alkali silicates produced will in addition differ in their coefficients of expansion from the bulk of the brick. Consequently it is suggested that the variations in temperature induced by the scurfing operation may result in some flaking of the surface layers. In other words, the presence of alkalies in the surface material of vertical retorts may be a contributory factor in the flaking of the refractory. It is, however, emphasized that this point of view has yet to be established.

The report deals only with preliminary experimental work on one particular aspect of the problem as a whole. It is confined to the action of the vapour from molten potash on various representative refractory materials at temperatures not exceeding 1000° C. Subsequently it is intended to experiment at higher temperatures.

Test pieces of four types of refractory material—an aluminous fireclay, a normal fireclay, a siliceous fireclay, and a silica—have been exposed to the action of potash vapour at 900° and 1000° C. The aluminous material at 900° C. absorbed potash the most readily, becoming at the same time mechanically disintegrated. An external viscous silicate which formed on the other fireclay materials appeared to act protectively. With the silica brick material, a fluid silicate was formed on the exterior which conferred no protection since it dropped off in the molten state at an early stage from the test pieces.

The extent to which chemical decomposition of the brick material had occurred was measured by treatment of the specimens with dilute hydrochloric acid, and weighing the undecomposed residue. With up to 55 hours' exposure, the aluminous material was affected the most, although the fireclay material at 1000° C., which had absorbed 38·5 per cent. K_2O after 95 hours, and was apparently only superficially altered, left a residue of only 37·5 per cent.

The rate of volatilization of potash from potash impregnated refractory materials at 1000° C. has been examined for contents varying up to 4 per cent. K_2O. The loss of potash from silica materials is many times more rapid than from products containing clay. A preliminary heating for 5 hours at 1200° C. results in the loss of

potash from fireclay materials at 1000° C. becoming almost negligible. Silica brick material treated in the same way still loses potash much more readily than impregnated fireclay material which has not been heated above 1000° C.

Flaking of Continuous Vertical Retorts.

By A. T. Green, F.I.C., F.Inst.P., and F. H. Clews, M.Sc., A.I.C.

Introduction.

In a previous paper, one of us, following a consideration of the condition of vertical retorts after an effective life, emphasized the zonal nature of certain of the troubles. The extent and the deleterious influences of these zonal actions vary very considerably.

In some cases, for instance, the working life of a carbonizing unit may be considerably reduced; in others, not seriously affected. Nevertheless, we have found evidence of such actions in all the vertical retorts which we have examined in different parts of the country. The flaking of the refractory material in a vertical retort belongs to this class of zonal troubles.

The Nature of Flaking.

Before proceeding to any description of flaking, it is essential to point out that practically all the continuous vertical retorts in this country are constructed of either a " straight " lime-bonded silica brick or a highly siliceous product (over 90 per cent. SiO_2). Flaking is, therefore, usually associated with these materials.

Flaking, which has been described in the above-mentioned paper, is a type of disintegration affecting the surface of the refractory in the upper zones of a vertical retort, usually from 6 to 12 ft. from the top, that is, in the top silica courses below the firebrick section. The " flakes " vary in thickness from mere films to $\frac{3}{4}$ in. or so, and the plane of fracture is generally almost parallel to the retort surface. Often they shew evidence of fusion. The progress of flaking is apparently continuous, for formation of flakes from an already affected surface has been noted. Further notes describing these flakes will be given later.

The incidence of the trouble is particularly intriguing, for the position of maximum flaking appears to coincide with the zone of maximum scurf formation. Again, the temperature gradient through the retort wall is very steep since the charge is comparatively cold. In fact, in passing through this zone the charge reaches and, possibly, proceeds through the plastic stage. Of course, depending on the nature of the coal, the travel of the charge at this zone may be intermittent, with a resultant periodic chilling effect to the retort wall. The position of the retort or zone of the retort with respect to the point of combustion in the combustion chamber is apparently another important factor. Retorts, or the portions of a retort—in the upper half—near the locality of combustion, are usually the more seriously affected. Retorts or portions of the retort which receive a lower and less variable flue temperature are not, usually, subjected to the same degree of flaking.

The scurfing operation, conducted at intervals varying from three weeks to three months, appears to be intimately associated with the phenomenon of flaking. Perhaps the first indication of this association is the observation that, during the operation, pieces of scurf, to which these flakes of refractory are attached, are often dislodged. Examination of such samples shews that the scurf, during its formation, has penetrated into the body of the refractory and has adhered very tenaciously. We have observed the scurfing of vertical retorts on many occasions and have frequently noted the high temperatures of the burning scurf, giving an incandescent appearance to the progressive combustion of this material. Thus, it is emphasized that the surface of the retort at the " scurf " zones is subjected, during this operation, to very rapid fluctuations of temperature, a condition which contrasts very strongly with that obtaining during the normal working of the retort. It seems to us then that the elimination of scurf produces both a high temperature and a severe strain on the surface of the refractory. The extent of the strain depends, in some measure, on the adhesion of the scurf to the refractory. Experience with different retorts carbonizing different coals suggests very strongly that the nature of the scurf varies considerably with the coal used and the carbonizing conditions, chiefly, including temperature. The tenacity with which the scurf is held to the surface varies very much in different settings. It is, however, certain that the penetration of the scurf into the carbonizing face gives a very rigid union of the scurf with the refractory. On the face of it there are definite grounds for believing that the phenomena associated with the formation and rate of growth of scurf have their bearing on the flaking problem. The control of these phenomena is, however, probably outside the economic operation of the retort.

Flaking usually shews itself in the early life of the retort. Signs have been observed after two or three scurfings. After twelve scurfings there is, generally, obvious evidence of its existence. The trouble, however, may have no influence on the effective working of the plant for as long as three years, when repairs may be essential; of course, we are aware that many retorts have worked as long as six years without the necessity of any serious repairs in consequence of flaking.

An Analysis of the Probable Cause of Flaking.

The factors of major and minor importance, which may influence the flaking of retorts, may be summarized as follows:—

(1) The impregnation of scurf into the retort surface, its adhesion thereto, and its elimination during the scurfing operation.
(2) The constitutional changes in the silica in the surface layers resulting from high-temperature scurfings.
(3) The weakening of the surface layer by alkali and other impregnations.
(4) The steep temperature gradients in the retort wall obtaining at the flaking zone during normal working and the chilling effects of intermittent travel of the charge.
(5) The rodding of the charge and of the scurf during the scurfing operation.

It is not our purpose to argue that the penetration of alkalies and other substances into the retort face does not influence the trouble in question. In fact, we express the opinion that the results of such impregnations, together with other actions taking place during the operation of a retort, do weaken the superficial material. However, to account for flaking solely by such effects appears to us to be very inadequate and to ignore the more obvious features of scurfing. To us, the most likely explanation, in the light of all the evidence, is in the phenomena associated with the formation of scurf and its elimination by the scurfing process. When inadequately controlled, the temperature of combustion of the scurf can be extremely high. The strain set up in the refractory by what appears to be the " pulling away " of certain portions of the scurf, together with the local high temperatures can, we think, readily account for the observed effects. As it appears to us then, flaking is a progressive weakening, due in considerable measure to the nature of scurf and the scurfing operation. Once cracks have been formed in the surface the rate of disintegration increases rapidly owing to the burning of the scurf in the body of the brickwork. This is well illustrated by the condition of the " back " side of some of the flakes. Again, it is evident that the nature of silica and its readiness to be converted to low specific gravity forms is not sufficient to account for the trouble. The behaviour of the sillimanite retorts is adequate vindication for this statement. However, we do not dispute that any such volume changes taking place in consequence of the conversion of silica can seriously aggravate the trouble.

We have already stated that accentuated flaking takes place in the localities of combustion in the chambers. It appears to us that this is due to the particularly high temperatures at these positions influencing both the adherence of the scurf and the temperature of scurfing.

We are not in a position to recommend to the Industry an alteration in the design of retort setting, which might react favourably in reducing this disintegration. It is

clear, however, that the scurfing operation demands every consideration. The reduction and careful control of combustion chamber temperatures during scurfing, the control of the amount of air admitted to the retort during this operation, the elimination of rodding, and the adoption of a scurfing schedule conceived in the basis of adequate experience should materially help to reduce flaking.

We have often been told that the higher temperatures of carbonizing have resulted in increased flaking. This might be expected from other observations mentioned above. It is not, however, the function of this paper to suggest that the lowering of combustion chamber working temperatures is good practice, or one which will eventually result in an overall economy of operation. Nevertheless, there can be little doubt that the careful control of combustion chamber temperatures to suit (*a*) the type of coal to be carbonized and (*b*) the scurfing operation will materially help in keeping down flaking troubles.

If our observations and arguments are correct, it is evident that the refractory material in the flaking zone is required to resist, amongst other things, the severe stresses and the high temperature resulting from the scurfing operation. Consequently, the mechanical properties of such refractory materials at high temperatures are involved. Again, if the adhesion of the scurf to the refractory is a factor, and if this adhesion depends on the penetration of scurf into the retort face, then the permeability of the refractory materials must be considered.

Behaviour of Cokes in the Open Grate

By Dr. E. I. LLOYD, A.I.C., F. BELL, and H. J. HODSMAN, M.B.E., M.Sc., F.I.C.

Complete gasification of coal is a cherished ideal but, pending its attainment, the use of coke remains a problem which cannot be evaded. Of the possible uses in this country, the view is advanced that the open grate is the most desirable. In no other country has this type of appliance so great a vogue. Fuel for the open grate is one of the largest items in the national fuel account. Household coal commands the highest price, and its replacement by smokeless fuel will make the most important contribution to the reduction of urban smoke. The gas industry is probably most favourably placed for cultivating this market, but the considerations outlined have not escaped the attention of active minds in the coke oven industry. In spite of apparently discouraging circumstances, some interesting products have been produced in coke ovens, and it is not to be assumed that oven coke will be unable to play an important part in this market. It seems opportune, therefore, to publish results which have been accumulated of tests on a wide variety of fuels.

When assessing the serviceability of a fuel for the open fire, it is necessary to consider a number of qualities, namely, its behaviour in transport, storage, ease of ignition, output of heat, ease of extinction, dryness, proportion and quality of ash.

Reactivity.

The avidity of all cokes for oxygen rapidly increases until the differences become incapable of recognition. In the experiments of Dent and Cobb, all the cokes examined were able in the time available to take up all the oxygen supplied to them at 800° C. Above this temperature the rate of combustion appeared to be determined solely by the rate at which oxygen reached the surface, and not by the character of the coke itself. Expressed in other words, all the cokes were equally " combustible " at temperatures above 800° C., that is, a red heat. For practical purposes, it is only at temperatures below a dull red heat that the reactivities of cokes to oxygen seem to have importance. Another implication of this conclusion is that the problem of burning a coke in an open grate is essentially the maintenance of an adequate temperature in the fuel bed at low rates of combustion, *e.g.*, by the adequate use of insulating refractory. The reactivity to oxygen then determines largely the ease of ignition. Experimentally it is easier and more convenient to determine the latter by measuring an " ignition temperature."

When considering the significance of " ignition temperatures " it is important to bear in mind that probably the surface of a commercial coke is far from uniform chemically, and that the atoms of carbon on the surface differ in reactivity to oxygen. Now the more reactive carbon atoms will react preferentially with the oxygen, causing a local rise in temperature, which will bring the more inert atoms into reaction. In the measurement of the ignition point, and in practice, it is not the average character of the surface, but the presence of specially active atoms which determines the temperature of ignition. This is clearly indicated by interrupting the measurement immediately after an ignition point is passed, and allowing the sample to cool down. If the measurement is repeated, it will frequently be found that the " second ignition point " so determined is higher than the first, shewing that the active portions of the surface have been removed in the determination of the " first ignition point." This preferential combustion and change of ignition point may be observed in blended cokes. On the other hand, the second ignition point may sometimes fall below the first, suggesting that combustion has removed a relatively inert film, and exposed more reactive material. From these considerations it seems that there is no merit in uniformity of reactivity throughout a fuel for the open grate.

When interpreting the significance of these " ignition temperatures " allowance must be made for the fact that the test is made on small particles, whereas in practice the fuel is in lump form. Moreover, bulk density of the fuel has an influence on ignitability, which increases with the sizes of the pieces of the fuel.

A coke which is apparently unreactive to CO_2 may nevertheless have an unexpectedly low ignition temperature.

Sometimes it is too readily assumed that the reactivity of a coke is a matter of temperature of carbonization. This is by no means true.

Ash and Moisture.

It is hardly necessary to stress the desirability of a minimum content of incombustible constituents. It is usual in giving analyses to state the percentage of ash, but more attention should be given to its relative volume, for the consumer judges the ash content by eye. Coke ashes vary greatly in bulk density, according to their composition. The bulk density can be easily measured, and from this the relative volume in ccs. per gram deduced. The product of the relative volume and the percentage of ash gives the volume of ash per 100 gms. of coke, and this is a measure of the cleanness of the coke as it appears to the consumer. Moreover, the light ashes are just those which are easily disturbed by air currents, and give rise to complaints of dustiness in use. Voluminous ash is objectionable in the fuel bed itself. By choking the fire it impedes air supply, and therefore combustion. It clings to the fuel and obstructs radiation. Heavy ash, on the other hand, falls away and is freer from objection. Heavy ash owes its density often to its content of iron oxide, and there is some evidence that this gives the fuel greater reactivity and ease of ignition.

Experiments shew that the reduction in the ash content gives an increased output of heat, roughly in proportion to the calorific value. As this normally varies within comparatively narrow limits, the advantage of clean fuel lies not so much in greater thermal efficiency as in greater output of heat and increased cleanliness—both factors open to the judgment of the consumer.

The temperatures attained in the open grate are rarely high enough to cause clinkering. The fusibility of the

ash, important though it is in the closed stove, can be neglected where coke is to be used in the open grate, which is therefore a very desirable outlet for cokes having fusible ash.

The tendency of some cokes to burn noisily and for pieces of shale to suffer disruption with explosive violence is well known, and is one of the most objectionable properties of some gas cokes. Whatever the cause, it is certainly not an inevitable property of cokes. It is usually unimportant in continuous vertical retort coke, but a dry-cooled horizontal retort coke was found to burn perfectly quietly.

Bulk Density.

The bulk density is a most important characteristic, which greatly influences the behaviour of a coke in the open grate, both in the stage of ignition and in normal combustion, where it is largely determinative of efficiency and output.

Cokes with a high bulk density are more difficult to ignite, as is shewn by the greater consumption of gas for this purpose. As such fuels are usually high-temperature cokes carbonized in heavy static charges, *e.g.*, in coke ovens, intermittent vertical chambers, and horizontal retorts, the reluctance to ignite is usually ascribed to their "unreactive" character. This is not always true. The reactivity to CO_2 and the ignition temperature of a vertical retort coke may indicate equal or greater unreactivity, whereas experience may shew it to be more easily ignited. This is more probably due to the low thermal conductivity of highly cellular coke, as a result of which its surface can be more easily heated to the ignition temperature.

The incidence of bulk density is illustrated in a striking manner by a series of experiments made with the cinders left in the grate after the extinction of a fire. It is known that such cinders, especially from coal, are usually very easy to ignite. The same observation can be made with coke. The half-burnt cinders left by a coke—even an unreactive oven coke—are much more easily ignited than the raw coke.

Although low bulk density is so advantageous in the matter of ignition and combustion of cokes, it is open to objection on other grounds; it involves loss of mechanical strength and increases the cost of transport and storage, a matter to which modern trends in domestic architecture have given considerable importance. In closed stoves high bulk density is definitely desirable if attainable without undue loss of reactivity to oxygen.

The view is advanced that those interested in the sale of carbonized fuels should not passively conform with the prevailing fashions in fireplace construction. The popular view that the modern barless grate possesses any superiority in efficiency has no foundation. It is better than what it replaced, and its popularity is largely due to its simplicity of construction and æsthetic appeal. That so crude an appliance serves is a tribute to the excellence of the house coal available in this country rather than to any special merit of grate construction. Therefore, although the tendency has been for investigators to seek a product adapted to existing grates, there are good reasons for pursuing the opposite course of educating the consumer to instal appliances suitable for the fuel.

The process of low-temperature carbonization represents efforts to produce a product which can be burnt in a grate designed for consuming coal. Experience has shewn that such fuels can be produced and have already acquired considerable popularity. So far, however, they have not been marketed at prices which encourage their substitution for raw coal, presumably owing to high costs of production.

If the consumer will instal suitable appliances he can at once widen his choice of fuel without paying a higher price for it. Indeed, in view of the higher thermal

TABLE I.—*Results of Experiments on Four Samples of High Temperature Coke*
SEE ALSO CHARTS 1 TO 8.

Test No.	Coke.	Treatment.	Gas Used for Lighting. Cu.Ft.	B.Th.U. Radiated per Sq.Ft. per Hour at 0°/0° Position.					
				15 Mins.	30 Mins.	45 Mins.	60 Mins.	75 Mins.	90 Mins.
1	2	3	4	5	6	7	8	9	10
VERTICAL FRONTED GRATE (V).									
1	Continuous vertical retorts	*Nil*	12·6	30	45	65	140	255	375
2	" " "	5 per cent. coal, 2½ per cent. tar	8·0	70	158	300	420	483	465
3	Horizontal retorts	*Nil*	22·2	71	64	64	87	118	165
4	" "	4 per cent. coal, 2½ per cent. tar	12·0	61	125	150	212	259	289
5	Coke ovens	*Nil*	17·0	47	114	232	334	399	399
6	" "	4 per cent. coal, 2½ per cent. tar	12·0	49	167	313	370	407	373
7	Intermittent vertical chambers	*Nil*	27·1	89	131	87	105	141	177
8	" " "	6 per cent. coal, 2½ per cent. tar	17·0	60	76	154	185	228	275
COKE GRATE (C).									
9	Continuous vertical retorts	*Nil*	12·3	31	67	107	174	270	309
10	" " "	5 per cent. coal, 2½ per cent. tar	8·0	45	173	314	370	340	..
11	Horizontal retorts	*Nil*	17·5	33	51	67	107	146	211
12	" "	4 per cent. coal, 2½ per cent. tar	9·0	36	78	123	190	232	259
13	Coke ovens	*Nil*	12·0	45	87	137	197	273	334
14	" "	5 per cent. coal, 2½ per cent. tar	9·0	27	126	225	319	372	379
15	Intermittent vertical chambers	*Nil*	17·0	29	60	83	103	145	204
16	" " "	2½ per cent. coal, 2½ per cent. tar	13·0	31	64	73	108	..	274

efficiency of coke fuels, he will lower the cost of the effective unit of heat. Moreover, the appliance, if incorporating a gas burner for ignition, will save domestic labour. Chimney sweeping will become unnecessary. The extension of such appliances would provide a considerable use for gas. If it became standard practice in a city of the size of Leeds to light fires with gas, there would be a new daily load of at least half a million cubic feet.

A Method for Increasing the Ignitability of Coke.

Attention has already been drawn to the conclusions of F. J. Dent and J. W. Cobb in the Gas Fellowship Report of 1927, that the differences in the reactivity of cokes to oxygen commonly recognized are detectable only below 800° C. Above this temperature all the cokes examined appeared to be equally "combustible." The implication of this conclusion is that the ignitability of a coke is dependent primarily on the character of the surfaces of the pieces. When the pieces have attained a red heat, combustion can proceed satisfactorily whatever the reactivity of the interior to oxygen. In experiments made to test these conclusions various methods have been tried to activate the surface of coke. The first experiments were made by Mr. G. A. Thompson, B.Sc. As a result of further work now recorded, it was eventually concluded that an effective treatment must involve the application of a skin of solid reactive material to the surface of the coke and no material seemed to be more suitable for the purpose than coal itself. The practical problem lies in the selection of an adhesive and the method of application. As it is undesirable to have an adhesive soluble in water, the choice is confined to those which are fusible, *e.g.*, pitch, tar, or paraffin wax. The cost of paraffin wax is prohibitive, and actually the experiments recorded below were made with No. 2 Road Tar kindly supplied by Yorkshire Tar Distillers, Ltd. Probably a tar distilled a little further would have been better.

It is known that repeated attempts have been made to increase the ignitability of coke by treatment with oils, creosote, tar, &c., but a slight experience will show such methods to be unsatisfactory. The reactive film should preferably contain non-volatile material.

The coke may be treated either with a pre-mixed paste of coal dust and adhesive or by the simultaneous application of a spray of coal dust and adhesive. Both methods have been tried, but the latter gave the best results.

Results of Treatment.

Experiments were made on four samples of high temperature coke. They had been made in (*a*) Continuous Vertical Retorts; (*b*) Horizontal Retorts; (*c*) Coke Ovens; (*d*) Intermittent Vertical Chambers.

After treatment, the cokes were tested in a vertical fronted grate and a commercial coke grate. The grate was charged in the usual way and the fire lighted with the gas burner, the gas consumption being noted. The progress of the fire was observed during the first 90 minutes by means of a thermopile fixed in the 0°/0° position. Sometimes the test was continued longer to observe the behaviour on replenishment.

The results are shewn in Table 1, and in the corresponding series of graphs, Charts 1 to 8.

In Chart 1, curve A shews the rate of emission of radiation when a high-class house coal was used. The coal was easily ignited, requiring only 2·6 c.ft. of gas, but the emission of heat increased only slowly and a thermopile placed directly opposite the fire after 1 hour registered only 115 B.Th.U. per square foot per hour. A similar result, curve B, was obtained with untreated vertical retort coke. Although, of course, this was more difficult to ignite—requiring 12·6 c.ft. of gas—the radiation from the coke at the end of an hour was greater than that from the coal. The low temperature coke (curve C) shewed a much more rapid rise than either, and after 60 minutes was radiating 475 B.Th.U. per square foot per hour at the 0/0 position. The corresponding figure for the treated coke (curve D) at 60 minutes was 420 B.Th.U. per square foot per hour, which rose to 483 B.Th.U. at 75 minutes. Actually, during the first 35 minutes the treated coke was radiating more intensely than the low temperature fuel. Both required almost the same quantity of gas for ignition—7 to 8 cu.ft. In Chart 5 the corresponding results are shewn when the tests were carried out in a commercial coke grate. Curve A shews the results for the untreated

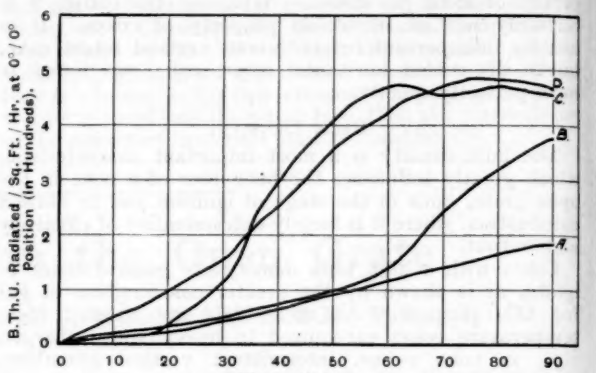

Chart 1 (Grate V).

Curve A.—House Coal.
„ B.—Untreated Vertical Retort Coke. Test 1.
„ C.—Low-Temperature Coke.
„ D.—Treated Vertical Retort Coke. Test 2.

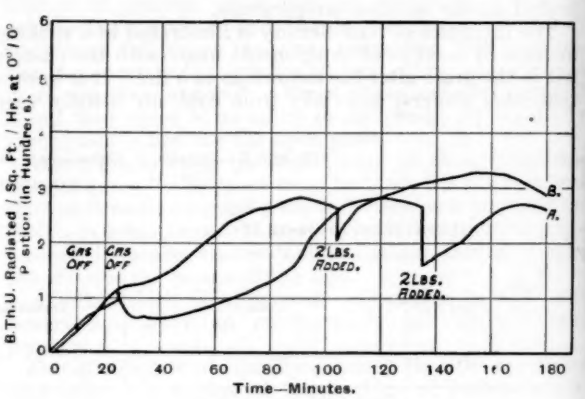

Chart 2 (Grate V).

Curve A.—Untreated Horizontal Retort Coke. Test 3.
„ B.—Treated Horizontal Retort Coke. Test 4.

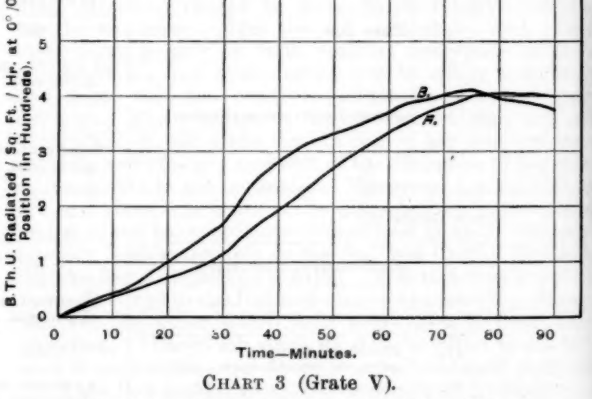

Chart 3 (Grate V).

Curve A.—Untreated Coke Oven Coke. Test 5.
„ B.—Treated Coke Oven Coke. Test 6.

vertical retort coke, curve B the result for the low temperature coke, and curve C for the vertical retort coke with the skin of coal. Here the radiation from the treated coke after 60 minutes fell only slightly short of that for the low temperature coke. The fire was re-

plenished at 75 minutes and recovered in 5 minutes. The effect of the treatment is clearly apparent.

Chart 2 gives curves for the untreated and treated horizontal retort coke burned in the vertical fronted fire. Curve A, for the untreated coke shews how the radiation

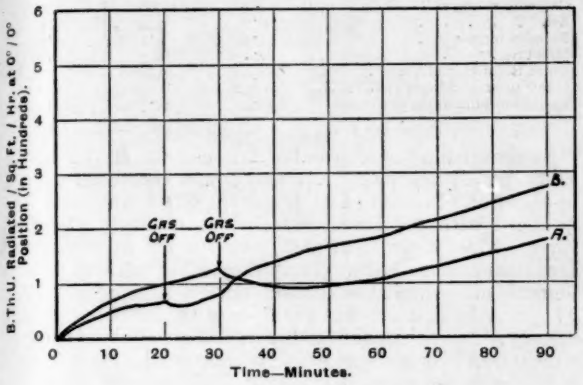

CHART 4 (Grate V).

Curve A.—Untreated Intermittent Vertical Chamber Coke. Test 7.
„ B.—Treated Intermittent Vertical Chamber Coke. Test 8.

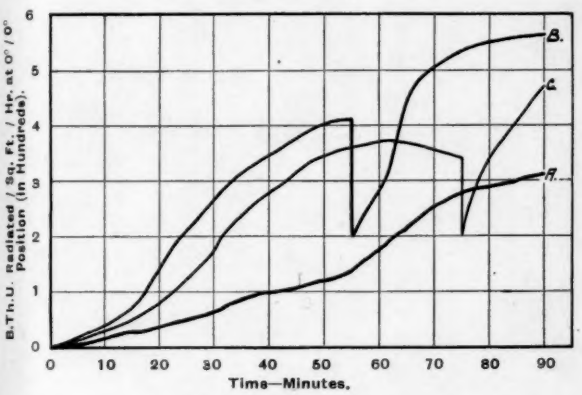

CHART 5 (Grate C).

Curve A.—Untreated Vertical Retort Coke. Test 9.
„ B.—Low Temperature Coke.
„ C.—Treated Vertical Retort Coke. Test 10.

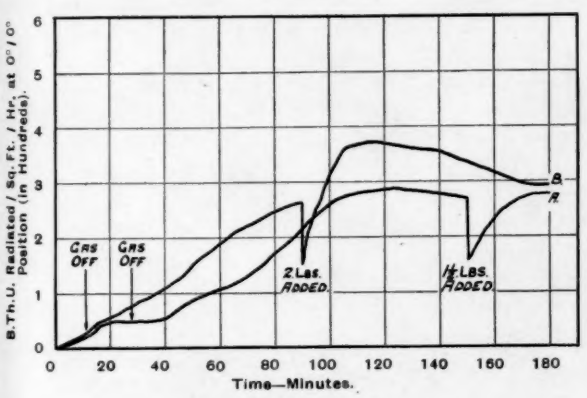

CHART 6 (Grate C).

Curve A.—Untreated Horizontal Retort Coke. Test 11.
„ B.—Treated Horizontal Retort Coke. Test 12.

falls immediately the gas is turned off, even though 22·2 cu.ft. had been used. The fire was replenished after 135 minutes, and it took some 30 minutes to recover. Curve B shews the radiation for the treated coke, and although only 12 cu.ft. of gas were used for lighting, the increasing rate of radiation was maintained after the gas was extinguished. The fire had to be replenished at 105 minutes, but it took less than 10 minutes to recover.

Chart 6 shews the results obtained with the horizontal retort coke in the commercial coke grate. The untreated coke, curve A, took 17·5 cu.ft. of gas for ignition and burnt up slowly. The fire was ready for replenishment only after 150 minutes. The treated coke, curve B, required only 9·0 cu.ft. of gas for ignition and was ready for replenishment at 90 minutes. It recovered

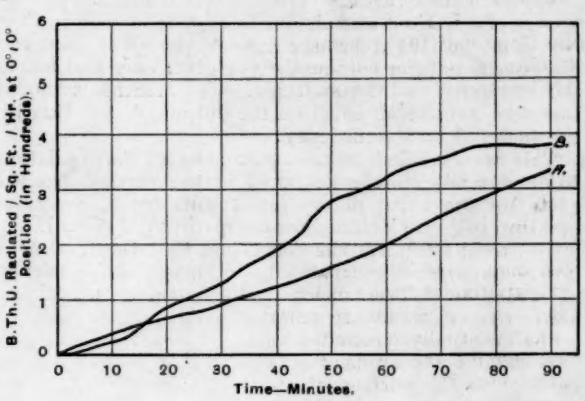

CHART 7 (Grate C).

Curve A.—Untreated Coke Oven Coke. Test 13.
„ B.—Treated Coke Oven Coke. Test 14.

then in 7 minutes, whereas curve A shews that the untreated coke required 20 minutes.

Chart 3 shews the results of tests on the coke oven coke in the vertical faced grate. The quantity of gas for ignition was reduced by treatment from 17 cu.ft. to 12 cu.ft., and the fire burnt somewhat better with the treated fuel.

Chart 7 shews the corresponding tests in the coke grate. The quantity of gas required for ignition was reduced by treatment from 12 to 9 cu.ft. As may be gathered from

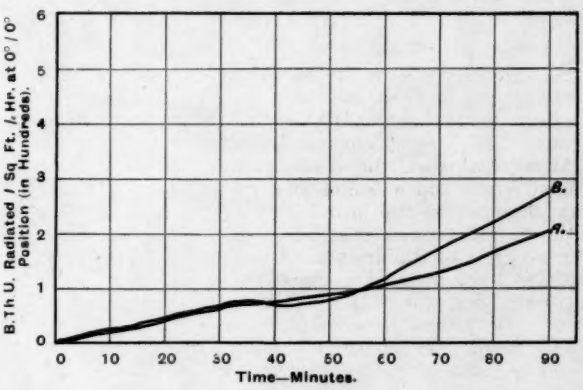

CHART 8 (Grate C).

Curve A.—Untreated Intermittent Vertical Chamber Coke. Test 15.
„ B.—Treated Intermittent Vertical Chamber Coke. Test 16.

the difference between curves A and B, the fire of treated coke burnt up much more quickly. The effect was more marked than in the other grate. It should be noted that this coke is not typical of metallurgical coke. Its bulk density is relatively low (26·8 lbs. per cu.ft.), and it is largely used as a domestic fuel.

Chart 4 shews the results given by coke made in intermittent vertical chambers, in the vertical fronted grate. The coke was slow to ignite (27·1 cu.ft.) and burnt sluggishly afterwards. After treatment, only 17·0

cu.ft. of gas was required for ignition, and the fire burnt up somewhat more quickly.

Chart 8 shews the results of tests in the coke grate where the benefit of treatment is seen to be small. Curve A (untreated) and Curve B (treated) for the first hour being almost identical. This coke had the highest bulk density (30·8 lbs. per cu.ft.) of any tested. It gave only a moderate performance in the radiation tests and now proved the least responsive to treatment.

Influence on the Radiation Efficiency of Fuel.

The output of radiation from a fuel is reduced by the presence of volatile matter and by high reactivity to CO_2. Now the effect of treating a coke as described increases the volatile matter to about 4 per cent. only and leaves the reactivity to CO_2 unaltered. The treatment should therefore have small effect on the output of radiation by the fuel and on its efficiency.

This was verified by measurements of the radiation from vertical retort coke burnt in the vertical fronted grate on the usual plan. The results for a low temperature coke are included for comparison. (Table II.)

The results confirm the conclusion that the treatment has not appreciably depressed the output and efficiency of radiation. The efficiency still remains appreciably above that of the low temperature coke.

Table II.—*Tests of Treated and Untreated Cokes.*

	Vertical Retort Coke. Untreated. Test 1 V.	Vertical Retort Coke. Treated.	Low Temperature Coke. Test 14 V.
1	2	3	4
Calorific value, B.Th.U./lb.	12,850	13,600	13,180
Ash	6·0	5·2	3·9
Volatile matter	1·6	4·1	12·9
Moisture	2·1	0·3	6.8
Total B.Th.U. radiated	55,920	55,620	45,720
Mean hourly radiation, B.Th.U.	9,320	9,070	9,270
Radiation efficiency, per cent.	36·2	34·7	28·9

Summarizing these results, it is clear that the ignitability of all the cokes examined was increased by the application of a skin of coal, but the effect was most pronounced with the coke made in continuous vertical retorts This, after treatment, was ignited as easily as a low temperature coke. The other cokes with high bulk density also shewed response, but to a smaller extent. This may be just another example of the influence of bulk density. It is the coke with a coarsely cellular structure which responds most readily to treatment. The treated coke emits some smoke during ignition and replenishment, but the quantity can be only a fraction of that from raw coal.

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